Palaeogeography and drainage evolution in the Gibson and Great Victoria Deserts, Western Australia

J S Beard

6 Fraser Road, Applecross, W A 6153
email: jsbeard@global.net.au

(Manuscript received May 2001, accepted November 2001)

Abstract

Data on the geography of the Gibson and Great Victoria Deserts were provided by vegetation and geological surveys published in the 1960-70's. Palaeodrainage maps were published by two different authors in 1973, but discrepancies between these could not be investigated until more altimetric data became available in the 1980's. Application of elevations to the palaeochannels and the general relief has revealed a number of anomalies attributed to epeirogenic movements thought to have been associated with repeated transgressions and regressions in the adjacent Eucla Basin. The Gibson and Great Victoria Deserts are situated on a Phanerozoic sedimentary basin, the Gunbarrel Basin, which overlies a much older Proterozoic structure, the Officer Basin. The Gunbarrel Basin contains a wide spread of Permian glacigene sediment capped with a lesser thickness of Early Cretaceous material. The adjacent Eucla Basin subsided later in the Cretaceous but the transgressions were not contiguous. Emergence of both basins followed and the Gunbarrel was substantially uplifted to form a plateau, the Gibson Plateau, of up to 400 m elevation sloping to the south. South-flowing drainages were initiated, forming the Keene, Carnegie, Throssel, Yowalga, Baker, Kadgo and Waigen Palaeorivers. In the north-west a single north-flowing drainage, the Disappointment Palaeoriver, was initiated flowing to the lake of that name. During the Eocene the Eucla Basin again subsided. Emergence which followed affected additional uplift of the Gunbarrel Basin by some 150 m, tilting the Gibson Plateau back towards the north. This resulted in the formation of basins of interior drainage in the Carnegie System and headwaters of the Throssell and Kadgo Systems, while other sections were rendered inactive by reduced grades. Decline of rainfall during and after the Eocene has since preserved this situation with all rivers inactive and subject only to siltation and salt-lake spreading. Downwarp of the Eucla Basin in the Miocene, and subsequent uplift which created the present Nullarbor Plain, seems not to have effected any modifications. There are no significant palaeochannels across the Nullarbor due to inactivity of the rivers further inland after the Miocene.

Keywords: Gibson Desert, Great Victoria Desert, palaeogeography, drainage

Introduction

The Gibson and Great Victoria Deserts (Figs 1 & 2) are situated in the remote, desertic eastern interior of Western Australia between latitudes 22° and 30° S. The Gibson Desert was named by the explorer Ernest Giles after his follower Gibson who was lost and perished there during Giles' unsuccessful attempt to cross the desert from east to west in 1873. After making a successful crossing further south in 1875, Giles named that area the Great Victoria Desert in honour of Queen Victoria, apologising for having discovered nothing better than a desert to name after her. Following the activities of the nineteenth century explorers, Forrest in 1874, Giles again in 1876, Lindsay 1891-92, Carnegie 1896-97, there was little further interest in the area for many years and it has remained largely uninhabited. The reason for this is not low rainfall - the average annual precipitation throughout the area is about 200 mm. The Gibson and Great Victoria are considered deserts as they are unsuitable for pastoral use. This is due to the underlying lithology of arenaceous rocks which produce sandy soils deficient in nutrients and a dominant plant cover of spiny grasses ("spinifex") unpalatable to stock. There is also a shortage of surface water and the topography is difficult, with most of the Great Victoria and part of the Gibson being covered with linear sand ridges.

To a large extent the two deserts cover the Officer Basin which originated by subsidence during the Proterozoic and became filled by up to 7 km thickness of sediments. Very little of these early deposits crop out, as the Basin continued to accumulate sediments sporadically during the Phanerozoic. During the Sakmarian stage of the Permian the highland areas were covered by an ice sheet and as the Officer Basin was still low-lying it was spread with glacigene sediments to a maximum known thickness of 450 m (Iasky 1990). These deposits are glacial or fluvio-glacial in origin, laid down in lacustrine and fluvial environments. They cover the whole Basin and form a large part of the outcrop. Later Permian, Triassic and Jurassic sediments are not found, but there is a widespread Early Cretaceous sequence, Valanginian to Aptian sediments up to 100 m thick,

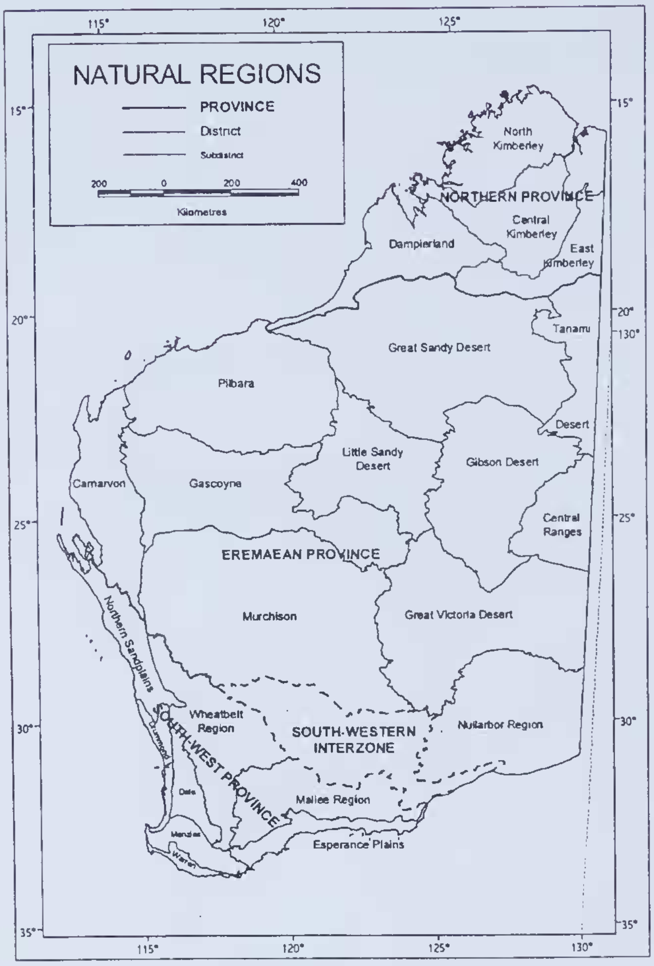


Figure 1. Natural Regions of Western Australia, after Beard & Sprenger (1984).

deposited in shallow sea conditions following a marine transgression. From the Late Cretaceous the Basin seems to have remained above sea level. An Eocene deposit, the Lampe Formation, is found only in channels in the Gibson Desert, and is not more than 5 m thick (Iasky 1990).

The Officer Basin, as a Proterozoic structure, has little bearing on modern topography and drainage. In recent work (Anon 1999) the area is called the "Gunbarrel Basin over Neoproterozoic Officer Basin". Its western boundary is taken as the line of continuous Permian outcrop but surface drainage is received from the Western Shield to the west of this. On the east the Basin is bounded by the outcrop of Proterozoic rocks forming part of the highland area of Central Australia, the Central Ranges region (Fig 1). The southern boundary is the northern limit of the Tertiary sequence in the Eucla Basin. These boundaries are shown in Fig 2A as accepted in 1973 (slightly modified since). On the north a basement ridge, the Warri Ridge, separates the Canning and Officer Basins, trending NW to SE. The approximate position is given by a line from the Warburton Mission to Lake Blanche on Fig 2A. This ridge has no present surface expression and does not coincide with the boundary between the surface drainage systems heading north-west through the Great Sandy Desert and south through the Gibson and Great Victoria.

The present topography of the Gibson Desert consists mainly of a plateau 400 to 550 m in height (the Gibson Plateau, a new name), which features extensive plains dissected at the edges and with occasional hill ranges, buttes and mesas. The plains have a laterite surface, apparently the remnant of a duricrusted soil profile from which surface sand has been removed by deflation and deposited in the valleys forming linear sand ridges. The laterite today is undergoing surface decomposition (Beard 1969). The Great Victoria Desert on the other hand is covered with east-west trending sand ridges occupying the southward slope from the interior plateaux of the Gibson and Warburton areas. The sandy desert ends at the boundary of the Nullarbor Plain at about 250 m above sea level. This boundary is accepted as that of the Eucla Basin. The Central Ranges region consists of two mountainous areas divided by a plain. In the north the Rawlinson group of ranges comprises mainly east-west strike ridges reaching 600 to 1000 m connecting with the Petermann Ranges of Central Australia. In the south the Warburton group consists of strike ridges in the west reaching 550-600 m and in the east of hills reaching 600-800 m. Between the two there is a sandy plain largely free of dunes and without organised drainage, standing at 500-600 m.

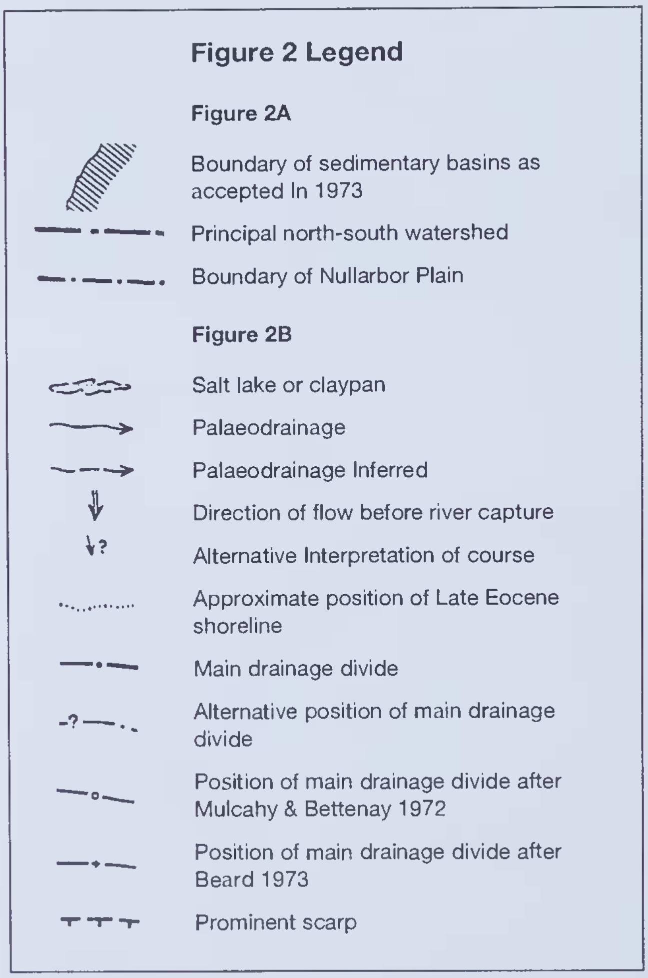
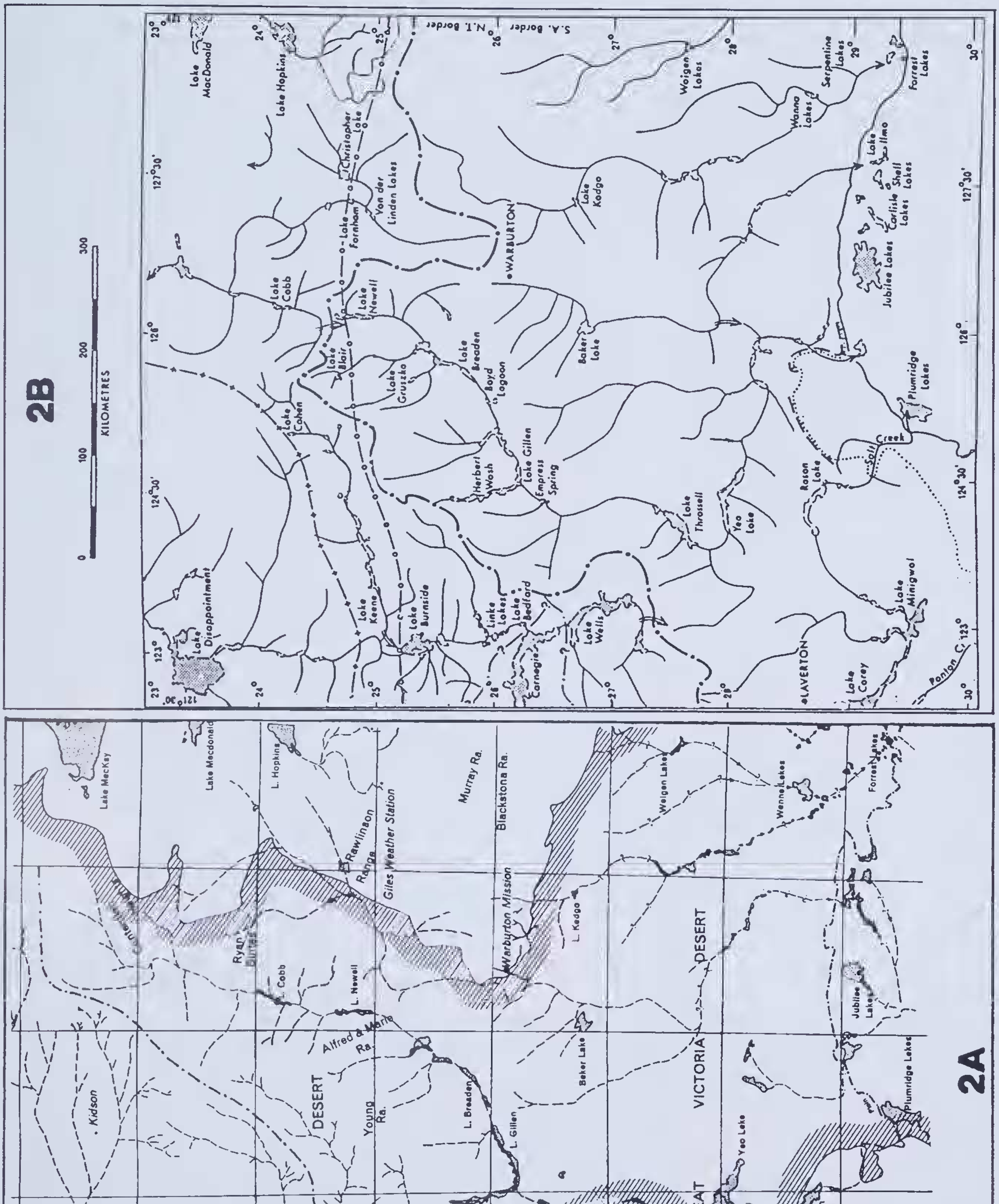


Figure 2. Previous treatments of palaeodrainage in the Gibson and Great Victoria Desert area brought to the same scale of 1: 5 000 000. A: Part of State map by Beard (1973); B: Slightly modified from Bunting *et al.* (1973).


2B
KILOMETRES
0
100
200
300
Lake MacDonald
Lake Hopkins
Lake Christopher
Von der Linden Lakes
Lake Fornham
WARBURTON
Lake Kadgo
Weigen Lakes
Wanna Lakes
Serpentine Lakes
Forrest Lakes
Lake Gillmo
Shell Lakes
Carlisle Lakes
Jubilee Lakes
Plumridge Lakes
Baker Lake
Lake Cobb
Lake Newell
Lake Blair
Lake Breaden
Boyd Lagoon
Lake Gruszka
Lake Cohen
Herbert Wash
Lake Gillen
Empress Spring
Lake Throssell
Yeo Lake
Rason Lake
Salt Creek
Lake Disappointment
Lake Keene
Lake Burnside
Linke Lakes
Lake Bedford
Carnegie
Lake Wells
LAVERTON
Lake Carey
Lake Minigwal
Ponton C.
N.T. Border
S.A. Border
2A
Lake Mackay
Lake Macdonald
L. Hopkins
Rawlinson Range
Giles Weather Station
Murray Ra.
Blackstone Ra.
Warburton Mission
L. Kadgo
Weigen Lakes
Wanna Lakes
Forrest Lakes
Jubilee Lakes
Plumridge Lakes
Kidson
L. Auld
L. Dora
L. Blanche
Disappointment
GIBSON
DESERT
Young Ra.
Alfred & Marie Ra.
L. Cobb
L. Newell
L. Breaden
L. Gillen
Baker Lake
VICTORIA
DESERT
GREAT
Yeo Lake
Lake Rason
Herbert Wash
L. Keene
Burnside
Buchanan
Carnegie
L. Wells
L. Throssell
Ernest Giles Ra.
Laverton
Lake Carey
L. Minigwal

A new era of exploration of these deserts began in the 1950s when geological and geodetic surveys began. The Commonwealth Government constructed a graded road from South Australia to Carnegie Station in Western Australia in 1956-58, and numerous other tracks were opened in the 1960s by government agencies and mining companies. A full coverage of aerial photographs became available from 1953. Publication of topographic and geological maps on a scale of 1:250 000 commenced in the 1960s. At the same time the present writer carried out sporadic field work and began vegetation mapping from aerial photography. Vegetation maps at a scale of 1:1 000 000 were published (Beard 1974, 1975) after some preliminary papers (Beard 1968, 1969, 1970). The 1969 paper drew for the first time actual boundaries for the desert areas derived from vegetation mapping, treating them as natural ecological regions (Fig 1). Since this mapping showed salt lakes, salt flats and other bottom land vegetation it was found that drainage patterns showed clearly although there are no currently active streams and rivers in the area. Streamflow today may be intermittent after exceptional rains or has become inactive, but it was clear that extensive valley systems existed which had been developed in the distant past. A palaeodrainage map of the whole State incorporating these data, scale 1:2 500 000, was published by Beard (1973), and the relevant portion for the Gibson and Great Victoria Deserts is reproduced as Fig 2A. At the same time geologists working in the area were able to use their mapping of alluvial deposits and knowledge of the topography to produce a palaeodrainage map (Bunting *et al.* 1973) which appears here as Fig 2B. These two maps have been reduced at the same scale for contrast in the Figure. Van de Graaff *et al.* (1977) later incorporated the geologists' map in a small scale palaeodrainage treatment for the whole State. The two treatments in Figs 2A and 2B are broadly similar. The principal and central drainage feature is the Throssell Palaeoriver, and to the east of it the Baker Palaeoriver. Both were named as rivers by Beard (1973) and revised to palaeorivers by van de Graaff *et al.* (1977). Further east are the Kadgo and Waigen Palaeorivers (new names). On the west side there is a drainage line running north-south along or close to the boundary of the Gunbarrel Basin and named the Disappointment Palaeoriver by van de Graaff *et al.* (1977). The northern part is directed north to the lake of that name but it was not clear whether the southern part which includes Lakes Carnegie and Wells originally drained north or south. Ground photographs of the landscapes in this area are available in Beard (1990). This paper follows other studies of geomorphology and drainage evolution in Western Australia (Beard 1998, 1999, 2000).

Methods

The purpose of this paper was to resolve, by using more recent data, several major discrepancies between the two previous treatments of the palaeodrainage, which were:

1. Bunting *et al.* (1973) cut off the headwaters of the Throssell Palaeoriver between Lakes Newell and Cobb, attributing this to river capture. Later when it became clear that there was no outlet to the north, van de Graff *et al.* (1977) attributed it to tectonic movement along the Warri Gravity Ridge, forming "the only true internal drainage system in Western Australia". The south-eastern tributaries which they included in this system were shown by Beard (1973) as flowing to the south to the Baker Palaeoriver.
2. Van de Graaff *et al.* (1977) cut off part of the headwaters of the Baker Palaeoriver, shown as deflected into the Throssell Palaeoriver at Lake Breaden.
3. Beard (1973) showed a relatively short unnamed drainage line leading north into Lake Disappointment. Drainages further south beginning with the Keene Palaeoriver and including Lakes Burnside, Buchanan, Carnegie and Wells were shown as heading south and connecting with the Throssell system. Bunting *et al.* (1973) on the other hand incorporated all these into a north-trending Disappointment Palaeoriver, while admitting that there were indications of a former southerly flow which had become diverted.
4. The outlet from Lake Throssell to the south was conjecturally shown by Beard (1973) as connecting with Lake Rason, but treated with more confidence by van de Graaff *et al.* (1977) with a different course passing through Lake Yeo.

Some other problems have called for clarification. Fig 2B shows that all the south-flowing palaeodrainages have substantial deviations to the east before reaching the Eucla Basin. Southward from Lake Wells the palaeochannel trends south for 100 km until suddenly taking a three-quarter turn northwards towards Lake Throssell. From the directions of flow the Throssell Palaeoriver can be inferred to have flowed south along this stretch until making a junction with the Lake Wells outflow at the sharp bend, the combined stream then flowing south and east. Instead, the combined stream is deflected east into Lake Yeo and then another 125 km to the east before turning south to the Eucla Basin. Where this river course parallels the scarp of the Eocene shoreline (Fig 2B) it is at about the same height but there is a ridge some 50 m higher between the two. Further east palaeorivers descending from Lakes Baker, Kadgo and Waigen show less strongly developed easterly deflections. To accord with modern practice, the forms Lake Yeo and Lake Baker are used instead of Yeo Lake and Baker Lake on older maps, *e.g.* Fig 2B.

The early work was hampered by lack of figures for heights. In the 1960-70s there were no contoured maps published, and spot heights were relatively rare. Beard (1968-75) operated without heights, relying on his mapping of the vegetation to show playa lakes, bottom-land vegetation of different kinds, and other indications of the topography. Van de Graaff *et al.* (1977) described the use of a grid of spot heights with a spacing of 11 km which had recently become available from gravity surveys. From these, 25 m form lines were drawn by hand on 1:250 000 scale maps, taking into account topographic and geological information available at the time. It was not possible to make any close check on the discrepancies in interpretation until more reliable altimetric data became available. This began in the 1980s when the Commonwealth began publication of a new series of 1:250 000 topographic maps which were contoured at 50 m intervals and had more abundant spot heights. The grid of Fig 2A represents the national grid used for 1:250 000 topographic, geological and vegetation maps. Issue of the new series of contoured maps was completed for this area between 1984 and 1989. A decade earlier the Geological Survey of Western Australia was working to produce geological maps at the same scale which were issued for this area between 1975 and 1979 and are very valuable in the present context for their mapping of surface deposits. In most cases the memoir accompanying each map includes a 'physiographic diagram' which shows form lines and a classification of physiographic units.

In the present study the contoured series of topographic maps was examined one by one, and relevant data on valley form, watersheds and heights were extracted on a reduction to 1:1 000 000. Each sheet was then compared with its corresponding geological map and the information in its attendant explanatory memoir. To assist interpretation, profiles of the principal palaeochannels were drawn, compared in the case of the Throssell palaeoriver with a profile of the western watershed of the Throssell catchment.

Results

To assist in clarifying the geography, a simplified map is given in Fig 3 showing the palaeorivers and their catchments outlined by the watersheds as ascertained in the present study.

In the course of studying the available data, it soon became clear that the situation was more complex than initially realised. Instead of a simple assessment of the discrepancies between the previous treatments, a thorough reappraisal of the geological history of the area would be required. This is detailed in the following sections, catchment by catchment.

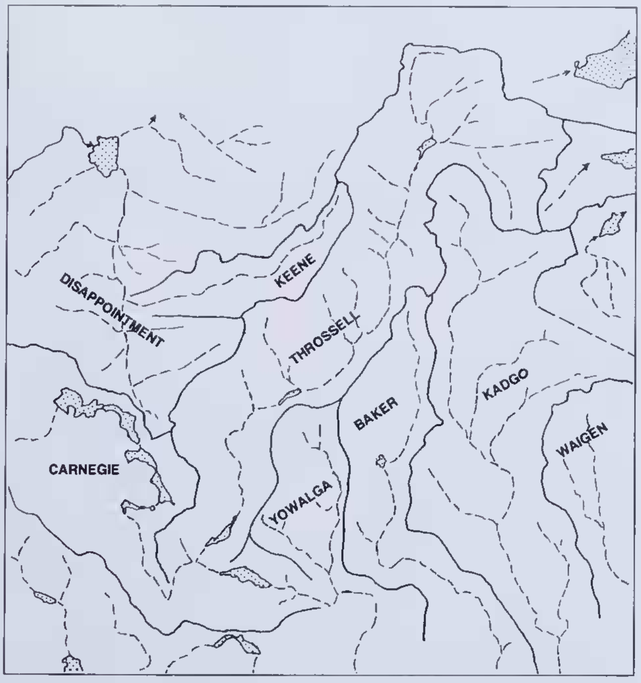


Figure 3. Palaeorivers of the study area (broken lines) with their catchments outlined by the watersheds (continuous lines).

Throssell Palaeoriver

The principal palaeoriver of the area is the Throssell, taking a south and south-westerly course through the Gibson Desert. Over 1000 km long, it is the longest river or palaeoriver in the State. Fig 4A shows a profile from the source of the main branch as far as Lake Yeo, a distance of 900 km. The lowest point on the profile is at a dry lake bed 170 km from the source at a height of 310 m, lower than Lake Yeo at 342 m. The uppermost part of the catchment appears to have subsided into an interior basin, as detected by earlier workers, although the alignments show clearly that it originally formed part of the Throssell system. At first sight on the topographic map the severance of the upper part of the Throssell palaeoriver appears due to an obstruction between Lakes Cobb and Newell associated with the Clutterbuck Hills, an outcrop of hard resistant sandstone of Proterozoic age up to 506 m in height on the east side of the valley. A similar hill is present on the opposite side of the valley but the outcrop is Permian (van de Graaff 1975). These hills cause a constriction and the valley between them is filled with sand dunes forming a col with a contoured height between 400 and 450 m *cf* Lake Cobb 342 m, Lake Newell 381 m. The col is probably due to no more than sand accumulation between the hills, and the profile in Fig 4A shows that this is not responsible for blocking off the upper part of the valley. There has been subsidence in the north or alternatively uplift in the south. South of Lake Newell as far as Lake Throssell the present surface of the palaeochannel is virtually level with heights varying only between 380 and 410 m over a distance of 410 km. The channel is probably substantially silted but depths are not known except for 101 m recorded at Lake Throssell (Bunting *et al.* 1978). South of Lake Throssell the palaeochannel falls 35 m in 80 km to Lake Yeo. It would appear that it is not only the uppermost section of the river course that has been affected by epeirogenic movement, as the course cannot originally have been level for 410 km.

To confirm this, a profile (Fig 4B) was constructed for the watershed which bounds the Throssell valley on the west side. This shows substantially the same outline. For the first 225 km from the north end it remains more or less level, on average 415 m from 12 spot heights, while the river bed deepens alongside. After the river reaches its lowest point the watershed also trends uphill rising from 410 m to 552 m in the Young Range over 140 km. South of this point it maintains a fairly even height again, averaging 518 m from 23 spot heights, as far as the Ernest Giles Range, a distance of 280 km. Here there is a further small increase in height, averaging 543 m from 14 heights over 180 km to reach the Truscott Hills. The watershed ends abruptly at Mt Venn, 500 m. South of this the palaeochannel from Lake Wells takes a sharp turn to the north-east in the direction of Lake Yeo. The watershed is continuous over a length of 920 km, mostly across gently undulating laterite plains with occasional hills, buttes and mesas. Apart from these it is often difficult to distinguish on the ground but can be positioned from mapping. This watershed is an effective indicator of the modern topography of the Gibson Desert and also of past epeirogenic movements. It is at its highest in the south, dropping in the north accompanying the basin formation of the upper Throssell palaeoriver. Van de Graaff *et al.*

(1977) attributed the latter to tectonic movement associated with the Warri Gravity Ridge, a subterranean feature formed in the Proterozoic, but since it is clear that wider movements have to be considered, it seems more probable that these were related to movements in the Eucla Basin.

Disappointment Palaeoriver

The channel running north into Lake Disappointment was so named by van de Graaff *et al.* (1977) who connected Lakes Carnegie and Wells to its upper reaches. Beard's (1973) map had shown this drainage, south of the confluence with the Keene Palaeoriver which comes in from the north-east, as flowing originally to the south and finding an outlet to Lake Throssell. Van de Graaff *et al.* (1977) agreed with this as the original alignment but considered that the system north of Lake Wells had been reversed to the north at a later stage. It is suggested here that this drainage line was originally formed after the end of the Early Cretaceous transgression by rivers which continued to discharge eastward off the Western Shield and were ponded at the break of slope at the former shore line. It is probable that flow took place partly to the north and partly to the south.

Examination of the latest maps shows a valley floored here and there by salt lakes and pans extending south from Lake Disappointment. Fig 2 shows this alignment, and a profile has been drawn in Fig 5A. The Lake itself stands at 325-330 m elevation. From it the valley trends fairly steeply uphill to the 400 m contour in 100 km (0.75 m km^{-1}) and then at a lower grade to Lake Burnside at 425 m in another 90 km (0.28 m km^{-1}). South of Lake Burnside the alignment continues uphill to Lake Bedford at 443 m and beyond to a source on high ground at about 480 m. There is no question therefore that this section represents the Disappointment Palaeoriver and that the tributary Keene River now belongs to it as it comes in north of Lake Burnside at about 395 m. Mapping however shows that there is not and has never been any outflow to Lake Disappointment from Lake Carnegie. This enormous salt lake, 120 km long and the largest in Western Australia, 441-444 m above sea level, is aligned slightly south of east turning to south-east at the eastern end. Between the latter portion and Lake Bedford there is a range of low hills of Precambrian rocks (Jackson 1978) about 470 m high with high points at Red Hill 474 m and Pt Katherine 513 m. There are gaps but none suggesting a connecting channel between Lake Bedford and Lake

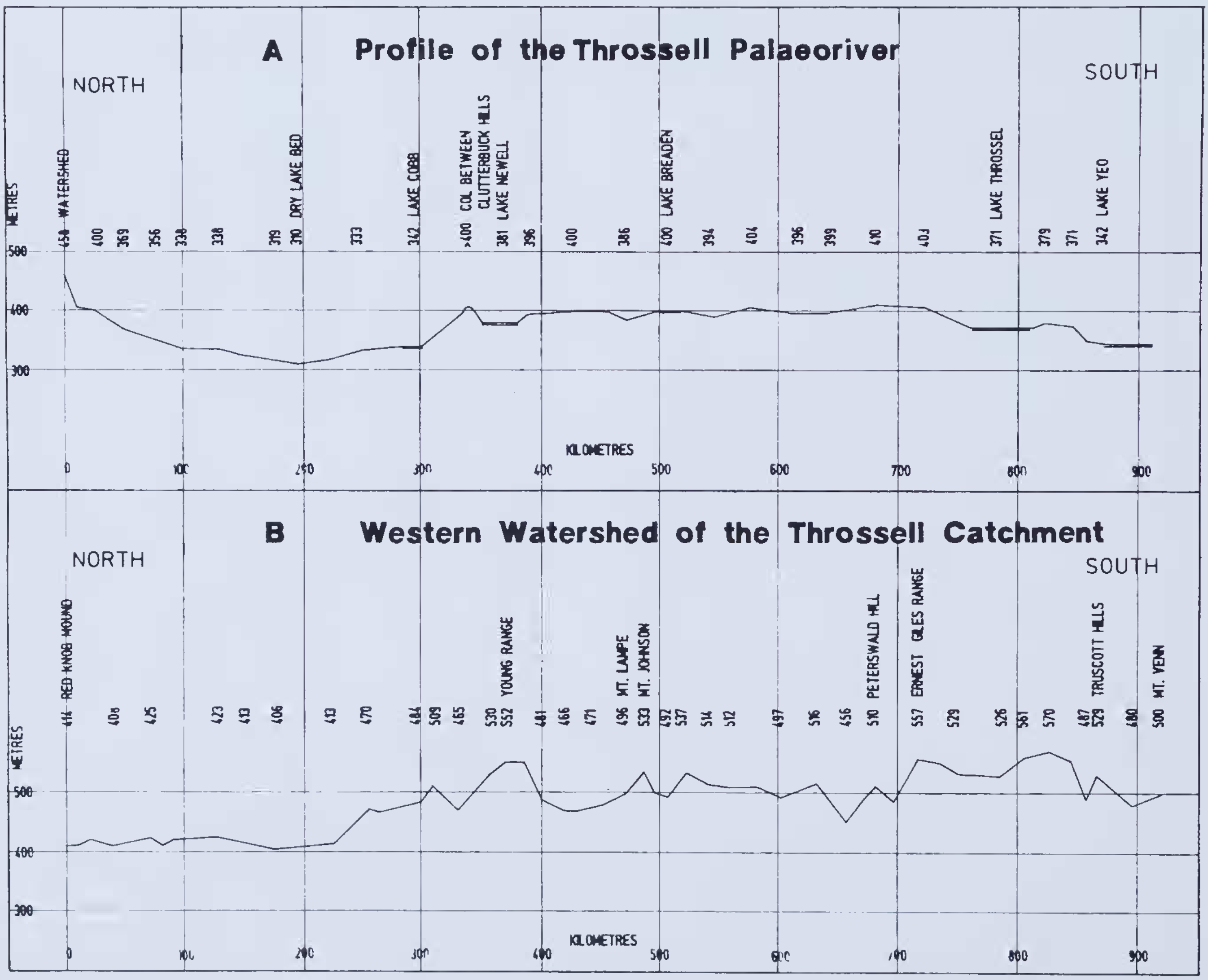


Figure 4. Throssell Palaeoriver. A: Profile of the palaeochannel; B. Profile of the western watershed of the Throssell catchment .

Carnegie, although the two are at much the same elevation. Further west, Lake Carnegie is cut off on the north by the Timperley Range and associated hills. It is much more likely that Lake Carnegie was connected to Lake Wells (441 m) on the south. There is an isthmus 5 km wide between the two due to another Precambrian ridge, but there are two gaps only 2 m higher than the lakes. Lake Wells trends southward for 80 km. The contoured map shows that there is no outlet further southward to Lake Throssell as suggested by Beard (1973) since a main watershed is interposed with heights exceeding 526 m. Instead, the alignment of Lake Wells swings to the west through an unnamed lake 35 km long and slightly higher, 451 m. At the western end of this lake there is again a well-marked drainage channel to the south, initially with greater spot heights of 464, 459 and 455 m. It takes 70 km to return to the same height as Lake Wells. The alignments however show that Lakes Carnegie and Wells must originally have flowed south this way and been affected by the same epeirogenic movements as the Throssell catchment, resulting in a similar profile to the Throssell (Fig 4B).

The drop at the north end of the palaeoriver into Lake Disappointment is more pronounced than that in the headwaters of the Throssell Palaeoriver, so much so as to suggest a downwarp at the site of the lake, although the descent may only represent the northern end of the Gibson Plateau. Lake Disappointment has been shown by previous authors with an outlet to the Percival Palaeoriver in the Canning Basin, connecting at Lake Winifred south of Lake Auld, which has spot heights of 261-263 m. This is about 65 m lower than Lake Disappointment but there is no obvious palaeochannel between the two. A line of lakes and pans leads to the east from the north-east corner of Lake Disappointment but without any indication of an outlet to the north to Lake Winifred. There are anomalies in the course of the Savory Creek before it joins Lake Disappointment at its north-west corner and it is possible that there has been diversion of drainage originally through the Rudall River by uplift of the hills. This however is beyond the scope of the present paper and should await a similar study of the Canning Basin.

Carnegie Palaeoriver

The Carnegie-Wells system (Fig 5B) is separate and may be named the Carnegie Palaeoriver. In its northern section, as with the middle course of the Throssell (Fig 4A) the alignment is level on the surface at the present

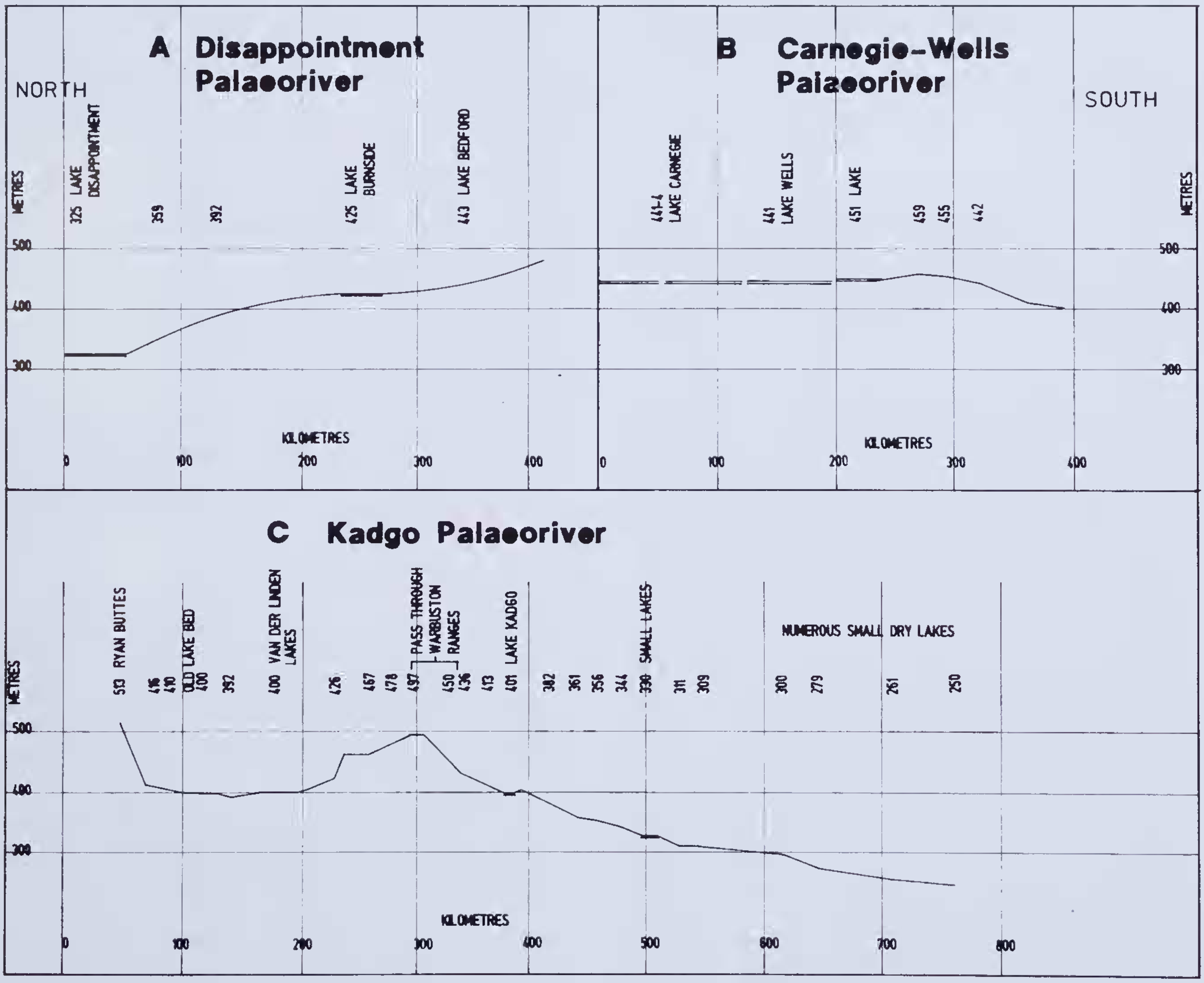


Figure 5. A: Profile of the Disappointment Palaeoriver; **B**: Profile of the Carnegie-Wells Palaeoriver; **C**: Profile of the Kadgo Palaeoriver.

day but there is a rise at the southern end in keeping with the watershed shown in Fig 4B. It is evident that the same epeirogenic uplifts have affected this palaeoriver equally and extended to the adjoining slope of the Western Shield. In particular while drainage was initiated following the first uplift forming the first rivers, these were ponded by the second uplift which had caused an obstruction at the south, and the lakes accumulated sediment and spread widely. North-west of Lake Carnegie there is a curious feature also related to this, a very large area of flat swampy ground at a height of 470 to 500 m and measuring 60 km south-west to north-east. It is a huge flat similar to Lake Carnegie but not so salted as to become a playa. The Oolgahroo Creek enters this from the north-west. No creeks can be distinguished on the flat, but it is drained by numerous creeks from its southern edge into Lake Carnegie. At the eastern end at Lake Augusta (456 m) flow starts to the east and becomes the Lalaline Creek, further down called the Coomborn Creek, leading into Lake Burnside and therefore part of the Disappointment Palaeoriver. However this cannot be construed as joining Lake Carnegie to the Disappointment system, rather the opposite. It appears to be a case of river capture and reversal. The alignment of the Keene Palaeoriver is to the south and south-west, taking a sharp turn to the north on joining the Disappointment Palaeoriver. The relatively steep slope of the latter north of this point suggests the likelihood of some river capture and it is suggested that the Keene did flow initially to the south and via Lakes Burnside and Augusta into the Carnegie-Wells system.

Kadgo Palaeoriver

The Kadgo Palaeoriver was shown by all previous authors as rising in the highlands of the Warburton area (Fig 2A,B) and finding its way southward via the Wanna Lakes to the Forrest lakes at the edge of the Nullarbor Plain. However the present study shows (Fig 5C) that it originally rose very much further north at the Ryan Buttes and came down through Lake Farnham and the van der Linden Lakes. Bunting *et al.* (1973) and van de Graaff *et al.* (1977) showed this northern section as reversed to the north by the same apparent downwarp affecting the upper Throssell palaeoriver and connecting with the latter some way north of Lake Cobb (Fig 2B) while Beard (1973) showed southerly flow as far as the van der Linden Lakes, escaping to the west from there to become the headwaters of the Baker palaeoriver. Map contours now show that both these solutions were incorrect. Actually the system rises in the Ryan Buttes (maximum altitude 480 m) and flows south to a spot height at 410 m, passes through a dry lake flat at 394 m, then a long distance level at about 410 m, an unnamed playa lake at 392 m, Lake Farnham <400 m and into the van der Linden Lakes at 400 m. Most of this stretch is level like the Throssell palaeoriver.

There is an east branch centred on Lake Christopher, about 400 m, which joins to the van der Linden Lakes. Drainage into it is derived from north and south of the Rawlinson Range. In addition a valley much obscured by sand ridges extends 50 km to the north to the foot of the Gillespie Hills and to the north-east for about 75 km between the Crocker and Carnegie Ranges. A valley leading south-east from Lake Anec terminates at a col of 450 m at 20 km from the lake. There is no possibility of a former connection between Lake Christopher and Lake Anec leading through to Lake MacDonald.

The south branch is a well-marked valley running south from the van der Linden Lakes to the Warburton Ranges. However, the present heights along this valley increase steadily towards the south from 411 to 497 m. At first sight therefore drainage cannot have escaped by this route and the van der Linden system must be another basin of interior drainage. It has been shown above, however, that the Gibson Plateau and the Carnegie-Wells Palaeoriver were both uplifted in the south, in the latter case disrupting drainage, and this movement may be assumed to have affected the adjoining Shield rocks to the east. As the above valley approaches the Warburton Ranges it begins to slope to the south. An active creek, the Lilian Creek, appears and passes through the Warburton Ranges at Snake Well between Miller Hill 570 m and Cassidy Hill 557 m in a gap 5 km wide. It passes 12 km further down, heading now south-east at Beal Outstation, through the Townsend Ridges in a gorge fronted on the north by the Lennard Bastion and on the south by a hill of 614 m. It cuts through these ridges at their highest point. The Lilian Creek here is clearly an antecedent stream and has functioned since the remote past. The creek soon dies out in the sandy desert but a palaeochannel is traceable for 50 km to Lake Kadgo (401 m) and beyond. In a further 50 km it falls to 360 m. In this 100 km stretch the grade is 1.4 m km^{-1}. After this the channel slopes at a lower grade, falling 60 m in 100 km. This is followed by a level stretch for 60 km perhaps representing the slight uplift further west which obstructs access to the south. Beyond this it again falls at 0.6 m km^{-1} to reach the Nullarbor Plain. The steeper slope south of the Townsend Ridges is in accord with a concept of uplift of the Warburton area, and the internal system further north becomes the headwaters of the palaeoriver to the south. A profile of the above alignment of the Kadgo Palaeoriver is given in Fig 5C, but it should be noted that it has also two palaeo-tributaries to the east which drained the plateau country between the Rawlinson and Warburton groups of ranges.

Yowalga, Baker and Waigen Palaeorivers

These southward flowing palaeodrainages have the same characteristics as the lower portion of the Kadgo Palaeoriver and call for no special description.

The Eucla Basin

The Eucla Basin subsided three times to receive accumulations of sediment, in the Early Cretaceous, Middle Eocene and Miocene, with intermediate uplifts (Hocking 1990). These are shown diagrammatically in relation to the Gunbarrel Basin in Fig 6. This figure shows a north-south profile of the two Basins at longitude 126° at six different stages;

A. Early Cretaceous transgression (Neocomian).

B. Cretaceous emergence (post-Cenomanian).

C. Middle Eocene transgression.

D. Post-Eocene emergence.

E. Miocene transgression.

F. Present day.

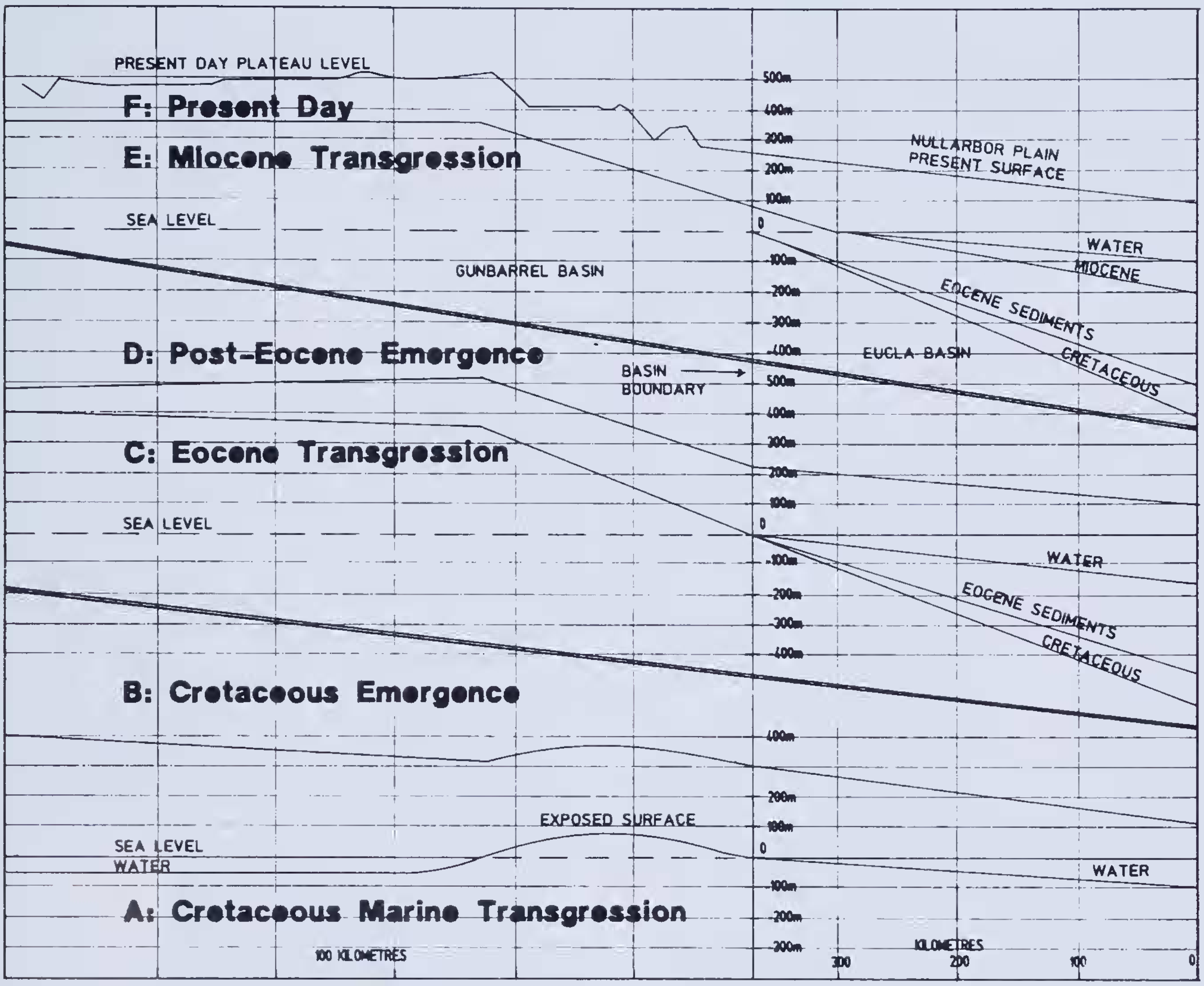
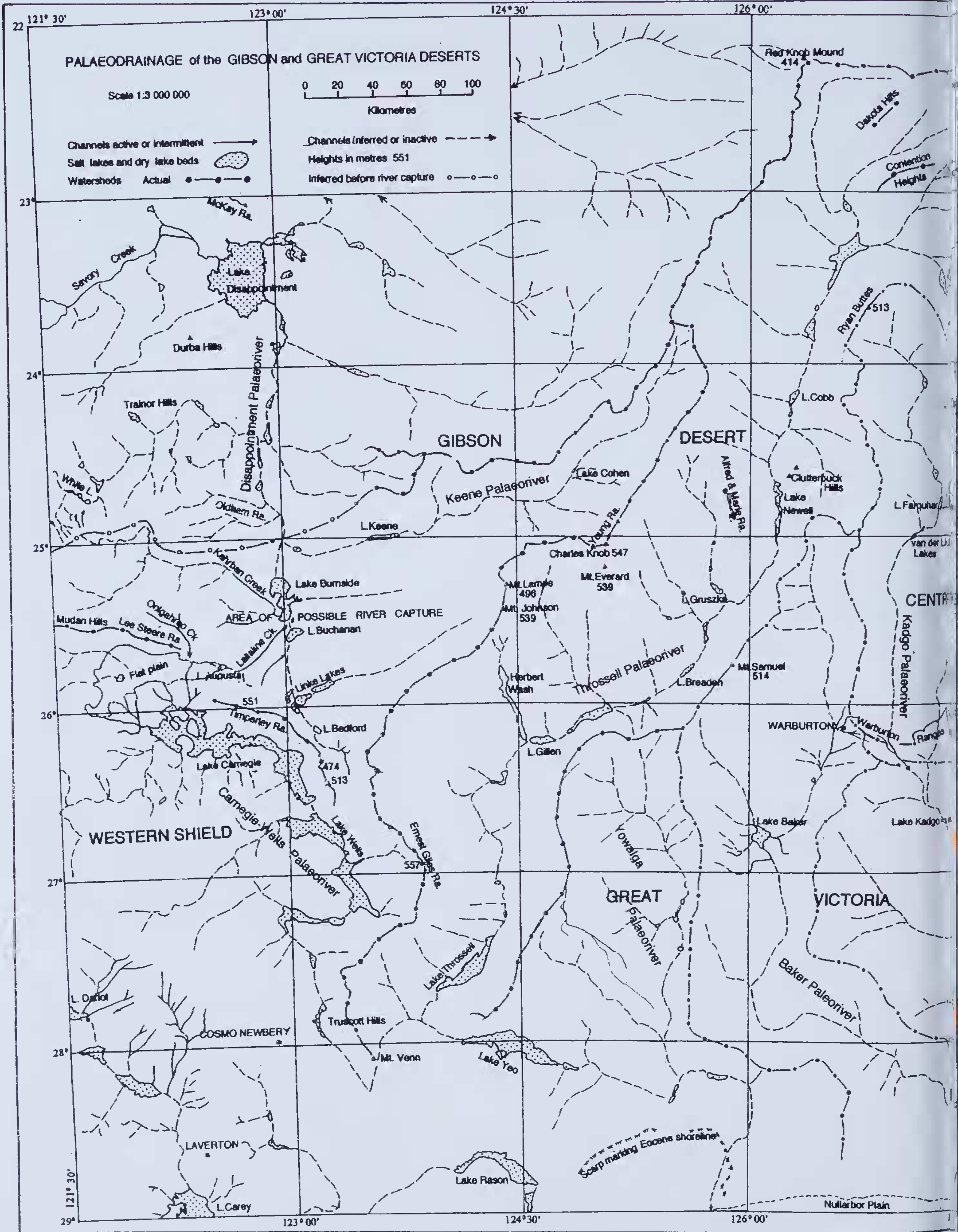


Figure 6. North-south profile of the Gunbarrel and Eucla Basins at different stages. A: Early Cretaceous Transgression; B: Cretaceous Emergence; C: Middle Eocene transgression; D: Post-Eocene Emergence; E: Miocene Transgression; F: Present Day.

Fig 6F, the Present Day, terminates the cycle with an actual measured profile along the watershed marking the eastern side of the Throssell Palaeoriver catchment from the Ryan Buttes at 23° 30′ S, 126° 30′ E for 550 km to 28°, thence in a straight line due south for 100 km to the edge of the Nullarbor Plain and on to the edge of the Great Australian Bight. The profiles of the other stages conform to this same line. The northernmost section of the profile stands at 530 m at its highest point and shows a slight fall from there to the north.

The tectonic movements involving transgression and regression are interpreted in terms of the Eucla Basin as a virtually unfaulted, southward-dipping sheet of sediment (Hocking 1990). No block-faulting was involved and we must assume gentle up and down warping of the Basin and its surrounding country. Attempts have been made to correlate high sea levels globally during the Cretaceous (*e.g.* Haq *et al.* 1988) but Western Australian examples show that tectonism must also be considered. In the Perth Basin on the western side of the Western Shield, a marine transgression took place in the Neocomian synchronously with the Canning and Gunbarrel Basins, until a regression in the Aptian. The Eucla Basin however only experienced a transgression later from the Barremian to the Cenomanian while along the south coast of Western Australia there is no evidence for Cretaceous transgression. In the Perth Basin the Aptian regression was brief and transgression returned until the Maastrichtian, but this did not apply elsewhere. The Eucla Basin together with the south coast of Western Australia experienced transgression in the Middle Eocene.

Effective history begins with the glaciation of the Early Permian when the Gunbarrel Basin was low-lying between areas of basement rocks on either side. Ice caps formed on these from which detritus was distributed generally over the surface of the Basin (Iasky 1990). During the Valanginian stage of the Early Cretaceous a widespread marine transgression covered the Canning and Gunbarrel basins with general deposition of sediments. At first, the seaway extended only from the Indian Ocean. The Eucla Basin began to subside later during the Barremian. The latest geological map of the State (Myers & Hocking 1998) shows Cretaceous sediments of this age extending generally as far south as 26° S (about equal to a line from Lake Carnegie to the


PALAEODRAINAGE of the GIBSON and GREAT VICTORIA DESERTS
Scale 1:3 000 000
0 20 40 60 80 100
Kilometres
Channels active or intermittent
Salt lakes and dry lake beds
Watersheds Actual
Channels inferred or inactive
Heights in metres 551
Inferred before river capture
121° 30'
123° 00'
124° 30'
126° 00'
22
23°
24°
25°
26°
27°
28°
29°
Red Knob Mound
414
Dakota Hills
Contention Heights
McKay Ra.
Savory Creek
Lake Disappointment
Ryan Buttes
513
Durba Hills
Disappointment Palaeoriver
Trainor Hills
GIBSON
DESERT
L.Cobb
Alfred & Marie Ra.
Clutterbuck Hills
Lake Newell
L.Farquhar
Lake Cohen
Keene Palaeoriver
White L.
Oldham Ra.
L.Keene
Young Ra.
Charles Knob 547
van der Linden Lakes
Mt.Everard
539
Lake Burnside
Mt.Lampe
496
Mt Johnson
539
L.Gruszka
CENTR
Mudan Hills
Lee Steere Ra.
AREA OF POSSIBLE RIVER CAPTURE
L.Buchanan
Kadgo Palaeoriver
Flat plain
L.Augusta
Linke Lakes
Herbert Wash
Throssell Palaeoriver
L.Breaden
Mt.Samuel
514
551
Timperley Ra.
L.Bedford
WARBURTON
Warburton
Range
L.Gillen
Lake Carnegie
474
513
WESTERN SHIELD
Carnegie-Wells Palaeoriver
Lake Wells
Ernest Giles Ra.
557
Yowalga
Lake Baker
Lake Kadgo
GREAT
VICTORIA
Palaeoriver
Lake Throssell
Baker Paleoriver
L. Darlot
Truscott Hills
COSMO NEWBERY
Mt. Venn
Lake Yeo
LAVERTON
Scarp marking Eocene shoreline
Lake Rason
L.Carey
Nullarbor Plain
121° 30'
123° 00'
124°30'
126° 00'

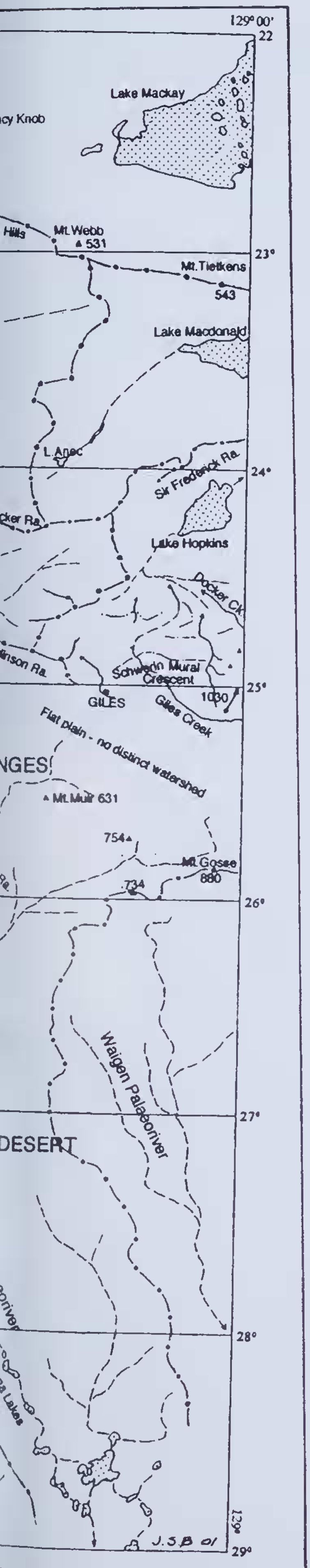


Figure 7. Corrected palaeodrainage map incorporating the results of this paper.

Warburton Range) with a tongue extending to 27° 30′ S. The rest of the western Gunbarrel Basin is shown with the outcrop as Permian.

Fig 6A shows a marine transgression covering both the Basins except for an emergent ridge between the two. After the Cenomanian, uplift of both Basins took place, a suggested movement of about 400 m, forming a plateau level in the Gibson Desert area, the Gibson Plateau, while the Eucla took on a slope to the south. The dividing ridge between the two remained. Formation of drainage and incision of rivers began. Those draining the Gunbarrel were obstructed by the dividing ridge and deflected to the east, probably due to a greater uplift on the west associated with an upward tilt of the adjacent Western Shield. The basic uplift of 400 m affected the whole region, the eastern margin of the Western Shield being raised by this amount. Beard (1998) showed that the Central Watershed of the Shield originates in the south at a height of 400 m, rising slightly northward. The Gunbarrel Basin must have experienced a similar tilt up to the north as initial drainage of the plateau was principally south. Drainage and erosion must have affected the Eucla Basin also but the landscape has been covered by later deposits. The Eucla Basin is shown in Fig 6 as not uniformly uplifted but taking on a slope to the south (Hocking 1990). In the Cretaceous, Australia and Antarctica had not separated fully. The basin deepened southwards and sediments thickened in that direction (Hocking 1990).

The next significant event was sinking of the Eucla basin during and after the Palaeocene, steepening the slope of the tributary rivers and causing renewed erosion so that an initial sequence of clastic sediments was deposited such as the Hampton Sandstone. As the tectonic movement stabilised, the deposits changed to limestone. "In the Eocene the Eucla Basin was a broad, arcuate, northward shallowing ramp, the margins of which approximated the present day basin margins" (Hocking 1990). The geological survey of the map Neale (van de Graaff & Bunting 1975) shows a feature interpreted as a modified wave-cut marine scarp at a present altitude of about 325 m which appears to represent the maximum extent of the Eocene transgression (Fig 6C). The Eucla Basin must have sunk as a whole, without block faulting, either uniformly or by tilting down to the north. In Fig 6B the Gibson Plateau is shown sloping slightly to the south with the original obstructing ridge in place. Both Cretaceous surface and basement take on a steeper slope because of the uplift. The former shoreline is assumed to be raised 325 m. With the Eocene transgression (Fig 6C) this returns to sea level but there is not a subsidence of the whole Gunbarrel Basin which remains uplifted and takes on a steeper slope to the south. The top of the slope on these diagrams agrees with the highest point in the modern profile (Fig 6F).

The next stage is the Post-Eocene emergence (Fig 6C). It is assumed that the Gibson Plateau did not sink again with the Eocene transgression. However, we also have to account for a further uplift of the southern part of the plateau by about 150 m as demonstrated in Figs 4A and 4B. It is suggested that this occurred with the Post-Eocene emergence and that the Eucla Basin rose by some 250 m to its present height. The surface of the Eocene deposits in the Basin is then shown sloping down to 100 m above sea level. The Post-Eocene emergence evidently involved a substantial uplift, shared with the whole southern coast of the State. The limited deposit of the Eocene Lampe Formation on the Gibson Plateau can be associated with disturbance caused by this uplift.

In the Miocene transgression (Fig 6E) the Eucla Basin did not subside as deeply as before and Miocene deposits are only 100 m thick. Following the transgression, the Basin rose to its present level (Fig 6F). As noted above, the profile in this figure is the actual one of the present day. It is possible that the additional uplift of the southern Gibson Plateau took place at this time instead of earlier, or alternatively that it rose at the end of the Eocene, subsided again wholly or partly and rose again after the Miocene.

It has been shown above that it is necessary to interpret the tectonic movements in the Eucla Basin as extending to the Gunbarrel Basin behind it. The uplift causing regression in the mid to late Cretaceous must also have uplifted the Gibson Plateau and the country on either side of it on the Western Shield and Central Ranges Region, and caused initiation of the palaeodrainage at that time. The second regression at the end of the Eocene further uplifted the inland country, essentially creating the modern topography as we see it. These events correlate with major movements elsewhere in Western Australia. Uplift of the whole Western Shield by 200-400 m appears to have taken place in the later Cretaceous (Beard 1998, 1999). Transgression occurred along the south coast during the Eocene (Middleton 1991) but not on the west coast. Late or Post-Eocene uplift was expressed in the formation of a marginal swell along the west coast with uplift of the continental margin by 150-200 m in a belt 80 km wide (Beard 1999, 2000).

Conclusions

Conclusions reached above are summarised as follows:

1. The two previous treatments of palaeodrainage in Figs 2A and 2B are in general agreement, with minor discrepancies.
2. Application of altimetric data recently available shows cases where palaeochannels are level over long distances or even have reverse slopes, indicating that tectonic movements have disturbed the original courses.
3. The palaeogeography of the area needs to be interpreted in terms of such movements in the Eucla Basin where marine transgressions implying downwarp occurred in the Early Cretaceous, Middle Eocene and Miocene, to be followed by uplift and regression (Fig 6).
4. The Gunbarrel Basin was invaded by the sea from the north in the Early Cretaceous from the Valanginian to the Cenomanian as far as 27° 30′ S (modern latitude). A transgression from the south affected the Eucla Basin slightly later from the Barremian. The two transgressions did not meet but were separated by an east-west ridge between 28° and 29°.
5. Uplift later took place. Initial development of the palaeodrainage patterns visible today must have taken place during the remainder of the Cretaceous since evidence elsewhere indicates that rainfall was high at that time whereas it declined markedly during the Tertiary. Considerable uplift of the Gibson Plateau is therefore postulated, perhaps as high as 400 m and with a slope to the south.
6. South-trending drainages were obstructed from direct access to the Eucla Basin by the east-west ridge referred to in paragraph 4 above, and were diverted to the east.
7. Silt carried by these drainages was transported to the south across the on-shore Eucla Basin.
8. The downwarp effecting the Eocene transgression may not have lowered the Gibson Plateau as a whole, merely steepened the south slope.
9. Following this transgression the Eocene uplift did affect the Gibson Plateau, mainly in the south, with an additional uplift of about 150 m, raising the plateau and its summits to heights similar of those of today. Decline of rainfall in the Tertiary reduced modification of the landscape.
10. This uplift disrupted the previous drainages but decline of run off meant that new outlets were not found. The Carnegie system was cut off in the south and formed into a basin of interior drainage, likewise the headwaters of the Kadgo and Throssell systems.
11. As the channels became inactive, siltation and salt-lake spreading became general.
12. No further modifications have been directly attributed to the Miocene transgression and subsequent uplift.

A corrected paleodrainage map for the area incorporating the above conclusions appears as Fig 7, compiled from topographic and geological maps. Principal palaeochannels are shown by broken lines and watersheds are indicated outlining the catchments. Hardly any of the palaeochannels carry drainage at the present day and most of them are choked with sand ridges. Active and intermittent channels are shown by continuous lines, chiefly in the northwest where the Savory Creek is the only active river on the map. Numerous small watercourses can be distinguished in aerial photography rising in the hills and ranges and quickly lost on the plain. These are mostly too small to appear in Fig 7. It is only in the more mountainous country of the Central Ranges Region that some longer watercourses of this nature can be distinguished, leading into Lake Hopkins which drains to the east into the Northern Territory. Otherwise palaeochannels have to be inferred from contours, from salt lakes, sand-free dry lake beds and calcrete deposits. These channels are in fact quite well marked although they have been extinct for most of the Tertiary, essentially since the Eocene with temporary renewals during pluvial periods.

Acknowledgments: I am indebted to Prof C D Ollier for critically reading the draft of this paper and to M Birrell for drawing Figs 4, 5 and 6.

References

Anon 1999 Western Australia Atlas of Mineral Deposits and Petroleum Fields. Geological Survey of Western Australia, Perth.

Beard J S 1968 Drought effects in the Gibson Desert. Journal & Proceedings of the Royal Society of New South Wales 51:39-50.

Beard J S 1969 The natural regions of the deserts of Western Australia. Journal of Ecology 7:677-711.

Beard J S 1970 The penetration of the western deserts of Australia. The Geographical Journal 36:557-568.

Beard J S 1973 The elucidation of palaeodrainage patterns in Western Australia through vegetation mapping. Vegetation Survey of Western Australia Occasional Paper No 1. Vegmap Publications, Applecross.

Beard J S 1974 The vegetation of the Great Victoria Desert area. Vegetation Survey of Western Australia 1:1 000 000 Series No 3. University of Western Australia Press, Nedlands.

Beard J S 1975 The vegetation of the Nullarbor area. Vegetation Survey of Western Australia 1:1 000 000 Series No 4. University of Western Australia Press, Nedlands.

Beard J S 1990 Plant Life of Western Australia. Kangaroo Press, Sydney.

Beard J S 1998 Positional and developmental history of the Central Watershed of the Western Shield, Western Australia. Journal of the Royal Society of Western Australia 81:157-164.

Beard J S 1999 Evolution of the river systems of the south-west drainage division, Western Australia. Journal of the Royal Society of Western Australia 82:147-164.

Beard J S 2000 Drainage evolution of the Moore-Monger System, Western Australia. Journal of the Royal Society of Western Australia 83:29-38.

Beard J S & Sprenger B S 1984 Geographical Data from the Vegetation Survey of WesternAustralia. Vegetation Survey of Western Australia Occasional Paper No 2, Vegmap Publications, Applecross.

Bunting J A, van de Graaff W J E & Jackson MJ 1973 Palaeodrainages and Cainozoic Palaeogeography of the Eastern Goldfields, Gibson Desert and Great Victoria Desert. Geological Survey of Western Australia Annual Report 1973:45-50.

Bunting J A, Jackson M J & Chin R J 1978 Throssell Western Australia, 1:250 000 Series Explanatory Notes. Geological Survey of Western Australia, Perth.

Haq B U, Hardenbol J & Vail R 1988 Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. Special Publications, Society of Economic Palaeontologists and Mineralogists 42:72-108.

Hocking R M 1990 Eucla Basin. In: Geology and Mineral Resources of Western Australia: Geological Survey of Western Australia Memoir 3:548-564.

Iasky R P 1990 Officer Basin. In: Geology and Mineral Resources of Western Australia: Geological Survey of Western Australia Memoir 3:362-380.

Jackson M J 1978 Robert Western Australia, 1:250 000 Series Explanatory Notes. Geological Survey of Western Australia, Perth.

Middleton M F 1991 Tectonic history of the southern continental margin of Western Australia. Record 1990/8. Geological Survey of Western Australia, Perth.

Myers J S & Hocking R M 1998 Geological map of Western Australia 1:2 500 000 (13th Edition). Geological Survey of Western Australia, Perth.

Van de Graaff W J E 1975 Cobb Western Australia, 1:250,000 Series Explanatory Notes. Geological Survey of Western Australia, Perth.

Van de Graaff W J E & Bunting J A 1975 Neale Western Australia, 1:250,000 Series Explanatory Notes. Geological Survey of Western Australia, Perth.

Van de Graaff W J E, Crowe R W A, Bunting J A & Jackson M J 1977 Relict Early Cainozoic Drainages in arid Western Australia. Zeitschrift für Geomorphologie N F Bd 21:379-400.